8. *Outdoor Part 15 Devices*

8.1. Introduction

From the analysis carried out in sections 5, 6 and 7, it is clear that the major interference problems concern the outdoor Part 15 devices. It is therefore instructional to investigate these devices further.

8.2. Interference Rejection and Selectivity

It is always possible to avoid interference by ensuring that two signals do not emit on the same frequencies, and/or emit signals at the lowest possible level. It is noted, however, that the Part 15.247 rules allow a much higher transmitted power level than has previously been permitted for unlicensed schemes[8] and, at the same time, couples that higher power with a wide band occupancy. The rules imply, therefore, that spread spectrum communications are particularly good at interference rejection and/or are particularly good at not causing interference.

The impression that spread spectrum communications are somehow immune from interference, and possess amazing spectral efficiency properties, is wide spread. The idea seems to exist that spreading the power over a wide bandwidth means that the demodulation/despreading process selects the wanted signal and rejects all others, and that the spread spectrum signal has an extra "processing gain" that is not possessed by narrow band signals.

In fact, if 1W is transmitted, 1W minus the propagation losses is received, irrespective of the spread bandwidth. The received power is contained in the final, or message bandwidth, which is the bandwidth required to demodulate the message, just as in conventional narrow band radio. The processing gain (PG) is the ratio of the spread bandwidth to the message bandwidth which is not an actual power gain, but can be considered as the equivalent to the channel filtering used in narrow band radio systems. The higher the PG, the better the rejection of unwanted signals.

[8]For example Part15.233 for cordless phones at 46.6MHz limits transmitted electric field strength to 10000μV/m at 3 meters. This is equivalent to a transmitted power of 30μW. As propagation loss is proportional to the square of the frequency, at 920MHz the equivalent transmitted power would be 12 mW.

The selectivity of the narrow band system is dependent upon the channel filter, which usually rejects adjacent and other channels by about 70dB. The equivalent to this for a spread spectrum system is the processing gain. Narrow band systems are subject to fading which is, generally, not the case with spread spectrum. This fading has a mean value of 10-20dB. Therefore, a spread spectrum system, in order to have similar selectivity, should have a PG of 50-60dB. Assuming a 3kHz final bandwidth, as required for simple analog voice for example, in order to have a PG of 50dB (i.e. 10^5) would require a spread bandwidth of 300MHz. If the system was used for higher data rates, requiring say 10kHz final bandwidth, then the spread bandwidth would need to be 1GHz.

Thus, it can be seen that spread spectrum systems used for communications actually require very wide bandwidth in order to be as robust as narrow band systems. The major difference is that with the narrow band system, the rejection (50-70dB) is only for <u>other</u> channels, and that any other radio on the <u>same</u> channel is not rejected, whereas with a spread spectrum system, all channels[9], and all other sources of in-band interference, are rejected equally, giving such systems, perhaps, their reputation for good interference rejection. Unfortunately, as shown above, a wide spreading bandwidth is required to achieve good interference rejection.

8.3. Typical outdoor Part 15.247 Specification - Jamming Margin

It is interesting to compare a spread spectrum and a conventional narrow band communication system, particularly with respect to the probabilty of mutual interference or blocking.

A typical outdoor Part 15.247, 900MHz device[10] has the following specifications:

Bandwidth	5.2MHz
Output power	800mW
Noise figure	8dB
Receive sensitivity	-95 dBm (BER 1 x 10^{-6}) 56 and 64 kbps
	-98 dBm (BER 1 x 10^{-6}) 1.2.to 19.2 kbps
C/I tolerence	0 dB
(Carrier over interference)	
PN sequence	32 bits
Chipping frequency	2.56 Mcps

[9] Different spreading codes are used to distinguish the channels.
[10] Airlink 64MP Multipoint Modem, Cylink Corporation.

In 5.2 MHz bandwidth , the thermal noise is -107 dBm. With a noise figure of 8 dB and a processing gain of 15 dB, a -95 dBm input signal will give a theoretical output signal to noise ratio of 16 dB. The jamming margin is the processing gain minus the output signal to noise ratio (in dBs). Hence the jamming margin is -1dB (C/I of 0dB is claimed).

With a jamming margin of 0 dB, this typical outdoor system is the equivalent of a single, 'narrowband' channel system 5.2 MHz wide, with no co-channel rejection[11].

Based on the above specification, the calculated range of the link is 1.78 miles[12]. In the specifications for this device, the range specification is as follows

Transmission Distance	Up to 10 miles with 2 Yagi directional antennas

It is questionable as to whether this type of specification is commensurate with the FCC rulemaking proposal which was intended for "low-powered, limited range devices"[13].

Three antennas are offered with the radio; a 2dBi omnidirectional, an 8dBi omnidirectional or a 10dbi Yagi.[14]. It is clear, therefore, that, in practice, the effective radiated power of these outdoor Part 15 devices exceeds the 6dbW limitation. Part 15.37 specifies that Part15.247 radios manufactured after June 23rd, 1994 must have an antenna that can not be (easily) changed by the end-user, and the transmit power adjusted to conform to the 6dBW limit. Whether end users will comply with this requirement remains to be seen.

[11]"Why part 15 equipment manufacturers object to rules proposed by Pactel ....", letter to FCC January 13, 1994, accuses the Teletrac system of being fragile. It should be noted that the jamming margin of the Teletrac system is over 20dB, compared to 0dB for the typical part 15.247 direct sequence spread spectrum device. In fact it is the Part 15 devices that are fragile.

[12]For antenna heights of 30 feet.

[13]101 F.C.C. 2d 420.

[14]This is the typical situation. Another example is the NLR-96 "Spread Spectrum Modem"for data rates up to 9600bps, has a 1W transmitter, 4.2MHz channel bandwidth and a sensitivity of -95dBm. The jamming margin of this device is also 0dB. Offered with this modem are "highly directional" 10dBi Yagi antennas for long range.

8.4. Comparison of outdoor Part15.247 system and narrow band system.

In order to transmit a 64 kbps data signal requires a bandwidth of about 130kHz (BPSK) or 64 kHz (QPSK). Channel spacing of 250 kHz could be used with conventional techniques. Thus, in a bandwidth of 5.2 MHz there would be 20 to 21 channels. This radio would have a 60 dB channel selectivity (70dB channel selectivity minus 10 dB fade margin) and an output signal-to-noise ratio of 15 dB. These figures equate to a near-far-ratio of 13.3. Thus, if the transmitter were say 1 mile away from its receiver, then another transmitter, on any one of the other 20 channels, would have to be within 400 feet to interfere. Any other transmitter on the same channel, however, would have to be over 2 miles away in order not to interfere.

The typical outdoor Part 15.247 device requires 5.2 MHz for a single channel and with a jamming margin of 0dB has a near-far-ratio of 1. Thus, if the transmitter were say 1 mile away from its receiver, then another transmitter, within 1 mile will interfere[15].

In any given area, therefore, for a data rate of 64 kbps, it is possible to have 20 times more conventional links than direct sequence spread spectrum radio links.

8.5. Number of channels

In the 902 to 928 MHz band, five 5.2MHz wide channels can be accommodated. In the same space one hundred and four 250 kHz wide channels can be fitted.

As is shown in the interference analysis, section 6, because of the two high power forward links used by the wideband LMS systems, there could be only 3 available channels, 2 of which might interfere with, or experience interference from the wideband LMS systems. The outdoor Part 15 radio link would generally be advised to move to the centre of the band. As long as the density of these devices is low, it is possible that they will be able to co-exist with themselves.

In the 10 MHz bandwidth, not used by the wideband LMS systems, forty 250kHz wide channels[16] are available as opposed to one spread spectrum channel. It raises the question as to the advisability of using spread spectrum with only 0 dB jamming margin.

[15]This is also shown in section 7.1.

[16]For 9600bps data rate, the channels spacing could be reduced to 25 or 50 kHz, giving at least 200 channels in 10 MHz.

8.6. Discussion of Outdoor Part 15 Devices.

The use of directional antennas can help but often, especially in telemetry type systems, an omnidirectional antenna is used at at least one central site. Unfortunately, high gain directional antennas are, in practice, being used in addition to the maximum transmitted power, in order to give the best possible signal to noise. This practice could proliferate, if many such systems co-existed in a small geographical area, as there is no jamming margin and users might boost their effective power in order to overcome interference from other Part 15 radio links[17].

The marketing of the outdoor Part 15 devices for relatively long range brings to question whether these type of devices fall under the original definition for Part 15, i.e. "low power, limited range devices".

The Part 15.247 specification applies to three frequency bands, 902-928 MHz, 2400-2483.5 MHz and 5725-5850 MHz. As discussed above, in the 900MHz band the Part 15 device might be advised to use the center of the band and thus avoid the possibilty of interference. The outdoor Part 15.247 devices would be better advised to use the other bands where there is much more bandwidth available and hence the possibility of either having more channels and/or designing spread spectrum radios with positive jamming margins[18].

8.7. Conclusions

The typical outdoor Part 15, 900 MHz radio is spectrally inefficient when compared to a narrow band radio. The interference from wideband LMS forward channels and the interference to wideband LMS reception acn be easily avoided by selecting a channel(s) in the center of the band. For short distance links, the power level and use of directional antennas should be encouraged.

For long distance links, the 2400MHz band offers much more bandwidth and thus a greater number of channels in addition to presenting the opportunity to design spread spectrum radios with a useful jamming margin.

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[17]The jamming margin of the typical outdoor Part 15.247 radio is 0dB and hence there is no rejection of co-channels signals.

[18]For example the Western Multiplex Corporation "Linx" radio is a T1 (1.544 Mbps) digital microwave radio in the 2.4-2.4835 MHz band.

9. Recommendations

1 - Part 15.247 radios should be able to be simply set to channels in the center of the band i.e.912-918MHz.

2 - When intended for long distance links, the Part 15.247 device should be encouraged onto the 2400 and 5800 MHz bands where there is more usable bandwidth and there is the potential for designing devices with reasonable jamming margin.

3 - The installation manuals for Part 15.247 devices should include a section that tells the user the device is liable to interference and/or liable to cause interference if an LMS system is operating in their area and that as a first choice channels in the center of the band should be selected.

4 - Recommended power levels and the correct use of directional antennas, for specific link distances, should be included in the installation manuals for Part 15 devices.

5 - Part 15.249 devices should not need any specific recommendations as for the 15.247 devices.

6 - Wideband LMS systems should be designed to accept a certain degree of desensitization from Part 15 devices.

7 - Part 15 manufacturers and users should co-operate to find the simplest method of overcoming any interference such that both systems are operable.

Time Division Considerations
for
Wideband LMS systems

Summary

Wideband location systems cannot share the same frequency band using time division, because:

a) there is no common ground for arriving at a set of universal specifications,
b) a tremendous amount of time on the network is wasted,
c) essential emergency voice communications is rendered unusable,
d) the system reliability and integrity, essential for public emergency services, is catastrophically compromised,

and e) the introduction of a new innovative service to the public will be fatally delayed.

The adoption of a time slicing scheme to enable LMS providers to share the same frequency band is basically against the rules of any practical TDMA scheme. Assuming that someone can take on the task of defining the basic time slots in terms of duration and quantity, and that the management and control of the scheme can be satisfactorily defined and carried out, it will still be highly probable that the basic and detailed design of each system would need to be redesigned in order to ensure an acceptable degree of efficiency. The reduced capacity and service that would result, coupled with the extra costs involved, would act as a significant disincentive. The reduction in the ability to offer full ancillary services within the band would render the service unattractive. The introduction of a time slicing scheme would delay the LMS implementation, possibly indefinitely, and effectively remove the most comprehensive[1] and the most highly developed systems from the market.

Time Division

It is generally agreed that two or more independent spread spectrum location systems cannot co-exist in the same frequency band. It has been suggested, however, that systems share the frequency band by utilizing a time division scheme.

Theoretically the sharing of the frequency band would be accomplished by assigning each of a number of users, the full spectral occupancy of the system, for a short duration of time called a 'time slot'. The unused time regions between slot assignments, called 'guard times', would allow for time uncertainty and act as buffer zones to reduce interference. Time is segmented into intervals called 'frames' and within each frame are a number of time slots relating to the number of systems sharing.

[1] The MobileVision design has been based, from the onset, on the interim rules and the most comprehensive marketing studies which established the real needs of the market.

Thus, for M systems attempting to share the spectrum, a 'frame' consists of M time slots, each T seconds in duration. Hence the frame time length is MT.

Basic problems in specifying time division

In defining, or specifying a time sharing scheme, two basic questions need to be settled:

a) Can the value of M (number of sharing systems) be fixed at the onset?
and b) What value should M be?

Whatever value is placed on M, this is the direct reduction in the capacity of each individual system compared to that system having the spectrum to itself. Can each system design be set for a certain number of time slots, or is it likely to change from time to time and from location to location? These basic design criteria will present an almost impossible task to the system designer who is trying to provide the capacity demanded by the marketing forces.

The time slot will also need to be defined as to:

a) how long?
and b) how accurate?

The length of each time slot will be important as it will govern the delays experienced by each system and will need to be compatible with the duration of each system's location pulse, which could vary from 1ms to 1sec. Who shares with whom? Are the time slices to be different in each city because different systems happen to be sharing? The accuracy of the time slot will need to be defined so as to set the guard time required. Systems using a shorter code length do not need to have such an accurate frequency control and hence time accuracy and although it may be possible to use a universal time source as the time-of-day clock at the fixed sites, it must be remembered that it is the mobile that will need to know the time and the mobile needs to be a cost effective unit.

It is important to note that the above considerations show that the time division system being considered here is <u>not</u> a TDMA scheme. In a TDMA scheme all users conform to a common approach and common standards and some form of system controller or control mechanism that manages the scheme is present. In this case we have, at present, four systems that are totally independent and which have totally differing parameters.

In considering time sharing for wide band LMS, the following conditions actually apply:

i) Each system uses different data rates and protocols.
ii) Each system uses a different duration for the location burst.
iii) Each system has been designed to be independent.
iv) Each system has different fundamental parameters.
v) Each system is considering different techniques in order to provide the necessary ancillary services.

The term TDMA conjures up the image of a well engineered, efficient data scheme where each user conforms to a well defined set of protocols. To the contrary, the sharing suggested for LMS is a crude time slicing scheme.

Time slicing results in significant dead time.

In order to make the time slicing work, it is necessary to introduce a forward scheduling scheme. This means that commands transmitted to the mobile instruct the mobile to transmit a location burst at a certain pre-defined time, which will be within an allocated time slot. Thus the mobile must know the time and needs to be constantly up-graded by the command channel. Such a scheme that requires updating by over the air data will be limited to an accuracy of about 10ms. Thus a guard time of at least 20ms will be needed. In addition there will be dead periods equal to the duration of a location burst, at the end of each time slice that cannot be used. As it is not permitted to transmit outside of the time slice it is not possible to begin a location burst that could continue beyond the end. Therefore in comparison to a constantly available channel, when locations can be scheduled continuously, the effect is, over a period, to create a 'dead time' that is up to the length of a location burst. Thus, in the case of Teletrac, for example, this could be in the order of 100ms, for MobileVision 55ms and for SBMS up to 1sec. This dead time reduces the capacity of each system even further. Time slice periods of 0.5 to 1 second have been suggested. If two systems are sharing then the capacity of each system will be reduced significantly below 50% as far as location pulses are concerned, and in the case of MobileVision to about 45%.

Data rate throughput is significantly reduced.

At 2400 bps data rate, messages of more than 100 characters will take longer than 0.5 seconds (assuming 50% overhead for synchronization, error correction etc.). Time slicing will impact on the data traffic such that smaller packets will be required. Each packet needs to be acknowledged. With time slicing the data messages will need to be cut up into packets that can safely be sent and acknowledged within the allocated time slice. As for location bursts, a packet cannot be started near the end of the time slice and therefore a 'dead time' exists which is the length of the data packet. Usually in radio data communications several packets are strung together with a protocol that calls for only those packets received in error to be re-transmitted. The time slice scheme will make the data protocols much less efficient because long transmissions will prove difficult to handle, because of re-transmissions and acknowledgments within the time slice, as well as causing long 'dead times' at the end of each slice. The data capacity will therefore be reduced by significantly more than the number of sharing systems.

Emergency voice service is fatally impaired.

It has been established by comprehensive and documented market studies that the services that LMS provides require ancillary data and voice communications. For example, the emergency roadside service (ERS) is not viable without emergency voice facility as well as the location and data service. Indeed, in a major market survey, 64% of respondents stated that voice was needed for the ERS service. Similarly, the studies showed that in commercial systems only 9% were interested in a location only service and 46% required voice to be available. Furthermore, a review of the IVHS documentation shows that real-time voice and data services are mandatory for the Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (CVO). Therefore, in order to be viable, LMS must provide all these services (location, data and voice) from one low cost vehicle unit.

Voice communications, within a time slice scheme, can only be achieved by compressing the voice, transmitting during the time slice, and then expanding again. With two time slices of, say, 1 second, this would mean that the voice would need to be compressed by more than half, which means that the frequency range more than doubles to, say, 8kHz , in place of 3kHz[2]. When received the voice is expanded back to 3kHz but there is a time delay equal to three time slice periods. The result is that not only is the capacity more than halved, because the required channel bandwidth is more than doubled, but also there is a time delay of 3 seconds on the voice. Even with a 0.5 second time slice the delay is still 1.5 seconds which is totally unacceptable. Documented market studies, and common knowledge, have shown that in an emergency situation, such as the ERS service, un-interrupted voice communication is demanded by the public[3]. Voice is virtually impossible in a time slice scheme notwithstanding its importance to the LMS service[4].

No common ground for producing a set of rules.

Given the above technical problems, and putting aside the problem posed by the voice component in LMS, how could the other issues be resolved? The only way would be to convene a committee consisting of all the interested parties which would, in turn need to create working parties to look at the various problems. If each party were willing to compromise, re-design their system and accept the substantial delay in getting to the market it could possibly work, but the reality of it is that some parties would have a strong

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[2] This is assuming an analog implementation. A digital voice implementation would require even more bandwidth. Both methods represent a significant cost penalty as well as time penalty.

[3] This would be comparable to a 911 service that was data only, i.e. without voice.

[4] MobileVision, and most of the other known wideband service providers, have designed systems that include a voice component or rely on the availability of voice on an adjunct cellular system.

incentive to delay the proceedings to offset the advantage gained by their competitors. Systems having longer pulse duration would suffer the most from time slicing.

Integrity and reliability of the service is catastrophically compromised.

While the negative incentive issues of sharing pose a significant problem, of even greater concern is the fact that the integrity of the system is totally compromised. Time slicing has been introduced into some paging systems which involve one way transmission using fixed sites. In the LMS situation, a multitude of mobile units are transmitting as well as fixed sites. The margin for problems is greatly magnified. When providing emergency services to the public it is mandatory that the highest system integrity be maintained. Time slicing introduces a total reliance on the integrity of other systems. If something goes wrong with any one of thousands of mobiles, let alone a fixed site, then the services of the other systems would be fatally compromised.

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Technical Review of the Virginia Tech Interim Report "Capacity and Interference Resistance of Spread Spectrum Automatic Vehicle Monitoring Systems in the 902-928MHz Band".

SUMMARY OF REVIEW

The Mobile and Portable Radio Research Group of the Bradley Department of Electrical Engineering at Virginia Tech have prepared an 'Interim Progress Report'[1] on the capacity and interference resistance of LMS systems. This interim report is based on a "review of the relevant technical literature and draws several qualitative conclusions regarding the performance of (LMS) systems". The conclusions and comments therefore are not based on specific scientific calculations or analysis.

MobileVision has studied the Virginia Tech report and, based on sound scientific reasoning and analysis (see "Details of Review"), offers the following comments and observations. In general, this MobileVision review:

- agrees with the report that the near-far ratio problem is too great to overcome when systems are directly overlaid.
- agrees with the report that time sharing by separate systems is "'unworkable",
- disagrees with the report that two adjacent systems, operating in each other's sideband, is practical:
    - significant interference does exist from the sidebands of a system,
    - the MobileVision system uses a full 8 MHz for location pulse and narrow band channels
    - operation in MobileVision's "sideband" will cause dramatic blocking of the other system,
- disagrees with the report that there are "insignificant disadvantages" in splitting 8 MHz into two 4 MHz channels:
    - the location capacity is reduced by a factor of four.
    - the data capacity is reduced by half
    - reducing the chipping rate reduces the ability to resolve multipath,
    - band filtering reduces the usable overall bandwidth ,
- agrees with the report that there is significant potential interference from *outdoor* Part 15 devices,
- agrees with the report that *indoor* Part 15 devices have much reduced interference potential.

The following more detailed technical review follows the sections as given in the Virginia Tech report, beginning on page 6. Each section is reviewed and analysis is given to support the position taken by MobileVision.

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[1]This report is sponsored by Southwestern Bell Mobile Systems (SBMS).

DETAILS OF REVIEW

1. Interference Issues

1.1. Co-Channel Interference for Direct Overlay.

The Virginia Tech MPRG report concludes that time sharing by separate systems would be '"unworkable" because the infrastructure would be unworkable and an inordinate amount of system capacity would be wasted.

MobileVision's conclusion is the same. The adoption of a time slicing scheme to enable LMS providers to share the frequency band is basically against the rules of any practical TDMA scheme. Assuming that someone can assume the task of defining the basic time slots in terms of duration and quantity, and that the management and control of the scheme can be satisfactorily defined and carried out, it will still be highly probable that the basic and detailed structure of each system would need to be redesigned in order to ensure an acceptable degree of efficiency from the scheme. The reduced capacity and service that would result, coupled with the extra costs involved, would act as a real disincentive. The reduction in the ability to offer full ancillary services, within the band, would render the service unattractive to the market. A full discussion of this subject is given in accompanying Appendix, "Time Division Considerations for LMS Systems".

In Annex 2 of MobileVision's Reply Comments, July 1993, an analysis was given of the SBMS Quiktrak system. In this analysis it was pointed out that the proposed SBMS system uses a unique FDMA scheme which means that the length of the location burst is long in comparison to the other systems. Thus the effect of time sharing on this system is even more problematic.

The Virginia Tech report also considers CDMA and concludes that the 'near-far' problem is too great to overcome. MobileVision's conclusion is the same and in Annex 4 of its Reply Comments (July 1993), the problem was fully analyzed using accepted propagation formulas. That MobileVision paper concluded that "the most damaging interference mechanism is related to the near-far problem" and that "The practical aspects of the near-far ratio......clearly show that simple sharing of the same frequency band, by two spread spectrum location systems will cause very harmful interference".

1.2. Adjacent Channel Interference Effects

This section in the Virginia Tech report discusses two areas:

i) the occupied bandwidth of the spread spectrum location pulse

and ii) the interference caused when two CDMA systems operate in the other's sideband.

1.2.1. Occupied Bandwidth

In the SBMS Comments, June 1993, it is suggested that the first sidelobes of the spread spectrum should be 20 dB down with each following sidelobe progressively reduced by 10 dB. Teletrac and Pinpoint both suggested that 99% of the energy should be inside the allocation. This is effectively the same as having the first sidelobes 20 dB down. Both Teletrac and MobileVision have included the first sidelobes within the allocated band and designed their systems accordingly. This point was discussed in Annex 1 of MobileVision's Reply Comments, July 1993.

MobileVision has carried out extensive research and development into this area and has developed techniques that utilize the entire 8 MHz. MobileVision had, from the onset, carried out its marketing surveys for fleet and consumer applications, and had thoroughly understood the IVHS requirements, especially Advanced Traveler Information Systems (ATIS), and Commercial Vehicle Operations (CVO), and realized that the location service was not viable without data and voice capability. Thus the MobileVision system was designed to include narrow band channels within the 8 MHz allocation. The actual band occupancy of the MobileVision transmissions is therefore a mix of the location burst and narrow band channels which uses the entire 8 MHz band very efficiently.

1.2.2. Sidelobe Interference

The Virginia Tech report states that 20-30 dB of margin will result in negligible interference between systems and therefore two CDMA systems can operate in the other's sideband. Virginia Tech, or SBMS do not seem to have realized that the MobileVision system uses the entire 8 MHz and has narrow band channels in the band. Thus splitting the band into 4 MHz pieces, as proposed by SBMS, or operating a system in the 'sidebands' of the MobileVision' system is not feasible.

However, in the absence of any figures or calculations from Virginia Tech, it is worthwhile carrying out a simple analysis:

Assuming

a) there are two, 2 Mcps systems adjacent to each other, in 4 MHz slots (as proposed by SBMS)

b) the first sidelobe is 20 dB down and that the second sidelobe is 30 dB down, then the total power, in the other 4 MHz slot, will be -22dB relative to the total power.

The thermal noise floor is -174 dBm/Hz and for 4 MHz bandwidth, is -108dBm.

At a fixed site, the received interference will be Pt - 22 - Lp (dBm),

where Pt is the transmitted power

Lp is the propagation loss

Using the 'Egli' propagation formula,

$$Lp = 114.7 + 20 \log F - 20 \log h1.h2 + 40 \log D$$

where F is frequency, MHz
h1 and h2 are antenna heights, ft
D is distance , miles.

Assuming h1 = 200, h2 = 6, F = 920.

then $$Lp = 112.4 + 40 \log D$$

For 10W signal, received level of interference is $40 - 22 - 112.4 - 40 \log D$, dBm
$= -94.4 - 40 \log D$, dBm

Assuming an antenna gain of 9 dB at the fixed site, and a 6 dB noise figure at the receiver, for raising of the noise floor, i.e. desensitizing the receiver

$$-94.4 - 40 \log D + 9 = -108 + 6$$
$$40 \log D = 16.6$$
$$D = 2.6 \text{ miles.}$$

Thus, any interfering mobile within 2.6 miles of the receiving site will desensitize the receiver site. This is significant as the site cell radius likely to be about 8 miles.

For the interfering signal to be 10 dB above the noise floor (thermal plus noise figure),or the sidelobes were 10 dB further down, then the result is 1.5 miles.

From the above simple analysis, Virginia Tech's use of the phrase "negligible interference" needs further clarification. These figures would indicate significant interference potential.

In addition, the fact that the MobileVision system uses the entire 8 MHz band for the location pulse and narrow band channels means that there is not, in the practical sense, a sideband at all and that bands of 4 MHz each will not be practical.

2. Bandwidth vs. Capacity

Virginia Tech argues that although the duration of a location burst must be increased by a factor of four if the bandwidth is halved, the amount of data transferred is only halved. They then conclude that, although there is a lower efficiency in location operations, "there is no disadvantage from sub-dividing this bandwidth for different systems". This is simply not true. Ignoring the factor of guard times, the total capacity of two systems is reduced by two, and the data throughput, within the location burst, remains the same. They seem to indicate that the effect of guard times will have some significant effect on the throughput of location pulses and reduce the four times factor associated with the pulse duration. The time between pulses will be set by the accuracy of the timing in the system. If a forward scheduling scheme is used, as it should be, so as to remove the effects of delays in the system, the guard times are related to the accuracy of the distributed time in the system, NOT the duration of the pulse. There is no reason why the distributed time accuracy should be related to bandwidth and hence no difference in guard times.

MobileVision fully agrees that the data capacity of the system is important, indeed it is paramount to the market success of the system. It is true that 'information' is directly related to the bandwidth. Although mentioning the guard times with respect to the location bursts, they do not seem to have considered the guard frequency, i.e. the band filtering, that is required if two systems are placed adjacent to each other. The band filtering required would reduce the useful band , in the order of 0.5 MHz, and therefore the overall effect is to have less usable bandwidth in two split bands than in the one wider band i.e. 7 not 8 MHz. This restricts the useful bandwidth, thus casting doubt on the Virginia Tech conclusion.

3. Effect of Channelization on Capacity.

Virginia Tech pointsout that the SBMS system uses FDMA which effectively provides 5 simultaneous location channels. MobileVision Reply Comments, July 1993, Annex 2 gave an analysis of the SBMS system. This analysis was based on assumed figures and calculated estimates. This analysis showed that the FDMA approach has advantages of jamming margin and range but had fundamentally significant disadvantages with respect to location capacity. The Quiktrak system was originally developed with 12 channels at UHF, (420 MHz), the adaptation of the system to 900 MHz reduces the number of channels to 5, and with it the proportional loss of capacity.

Virginia Tech made no comments on the significance of the FDMA. Since system capacity was a primary subject of the report one is naturally critical of Virginia Tech's assertion with respect to SBMS's capacity especially when that assertion is accompanied by no further support.. There has been plenty of opportunity to either concur or disagree with the MobileVision analysis.

4. Effects of Bandwidth on Multipath.

Virginia Tech correctly points out that the system bandwidth must exceed the coherence bandwidth of the channel, in order to resolve the multipath components. This is true but when applied to spread spectrum location it is different than when considering communications. In a typical urban environment, measurements of time dispersion at 900 MHz have shown that an rms spread of about 4 μs is common and that the maximum delay spread is typically 16μs. Coherence bandwidth, for the case where the envelope correlation is 0.5 is given by the formula:

$B_{0.5} = 1/2\pi\Delta$ where Δ is the standard deviation of the delay[2]

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[2]This was given in an appendix to the SBMS Reply Comments entitled "Remarks on Comments made by ...(Teletrac) and ....(Pinpoint)...".

Thus, from this formula, the coherence bandwidth is in the order of 10-40 kHz. Note that the higher the delay spread the narrower the bandwidth. Thus, if the argument is taken forward, the worse the multipath, the bigger the spread of signals, the lower the coherence bandwidth and hence the slower the chipping rate required for the spread spectrum location burst. This argument is obviously wrong. It is the minimum multipath spread that the system wishes to resolve that defines the bandwidth required. In the case of communications it is the maximum delay that the system can accept that defines the bandwidth and usually this is related to the bit period i.e. the data speed or the detection bandwidth.

In a practical spread spectrum location system the ability to distinguish between different received multipath signals is ultimately defined by the chip period. Multiple signals received at time differences less than the chip period are difficult to distinguish and tend to corrupt the correlated pulse. Multiple signals that arrive with time differences larger than the chip period can possibly be distinguished since ideally they are seen as separate correlated pulses. Thus the chip period defines the limit, the shorter the chip period the better the ability to resolve the multipath. Thus, if it is desired to resolve multipath signals 500ns apart, the chip time needs to be better than 500ns i.e. a chipping rate of 2Mcps. A chipping rate of 1Mcps has a limit of 1000ns. 1000ns corresponds to 1000 feet error and this is obviously not acceptable for the market place (i.e. emergency services and stolen vehicle recovery).

The transmitted pulse consists of several correlations and it is hoped that the multipath effect is reduced by averaging over a number of correlations. If the vehicle is stationary and/or in a particular location, this is not always possible. There are basically two forms of multipath error; variable multipath which is mainly due to the combined effects of vehicle movement and multipath effects, and multipath bias, which is a slower effect.

On each correlation, therefore, a system with a chipping rate of 1Mcps cannot detect a multipath signal less than 1000ns on the correlated pulse, and a system with a chipping rate of 2Mcps cannot detect a multipath signal less than 500ns on the correlated pulse. In practice delays greater than the chip period are required before they can be separated. Thus, although variable multipath can be significantly reduced by averaging, bias multipath cannot. The faster the chipping rate, the better the ability to resolve the multipath components.

5. Interference with Part 15 Devices.

MobileVision supports the points made by Virginia Tech in this section, however, little attempt to quantify the interference has been made. The following simple analysis is provided to indicate the potential interference problem:

5.1. Interference with outdoor Part 15 Devices.

5.1.1. Desensitization of LMS fixed site by outdoor Part 15 device

In a 4 MHz bandwidth the thermal noise is -108 dBm.

Assuming
Part 15 transmitter power is Pt dBm,
distance to the location system's fixed site is D,
then, using the 'Egli' propagation formula, the received signal level is

$$Pr = Pt - 114.7 - 20 \log F + 20 \log h1.h2 - 40 \log D \qquad \text{dBm}$$

for h1 = 200ft, h2 = 12 feet, Pt = 30dBm (1W), F = 920MHz

$$Pr = -76.4 - 40 \log D \qquad \text{dBm}$$

Assuming that the fixed site antenna gain is 9 dB,

$$Pr = -67.4 - 40 \log D \qquad \text{dBm}$$

Assuming that the fixed site has a 6dB noise figure, in order to desensitize the site the received signal needs to be -102dBm or greater,

thus $$40 \log D = 102 - 67.4 = 34.6$$
$$D = 7.3 \text{ miles.}$$

Therefore any outdoor/rooftop 1W Part 15 device, within 7.3 miles, has the potential to desensitize the fixed site station if it is in-band. For a 20 dB desensitization (-82dBm), the distance becomes 2.3 miles. A 20 dB desensitization represents a reduction of 3 in the range of the site.

These devices could present a real problem and as there are several on the market offering high gain antennas as part of the system, the practical problem may be higher. It is, of course, a simple matter to avoid, with co-operation between the LMS and Part 15 providers. If these devices were tuned to the center of the band (915 MHz), then they would not interfere, and also the correct use of transmitted power levels and directional antennas could reduce the interference potential significantly.

5.1.2. Desensitization of outdoor Part 15 device by LMS mobile

Similar to the analysis given above , the received level from a 10W, LMS mobile will be:

$$Pr = 30 - 114.7 - 20 \log F + 20 \log h1.h2 - 40 \log D$$

For $h1 = 12$, $h2 = 6$ $Pr = -106.9 - 40 \log D$

A typical receive sensitivity for an outdoor Part 15 device is about -90dBm.

Hence, for desensitization	$-90 = -106.9 - 40 \log D$
	$D = 0.38$ miles
For 10dB desensitization	$D = 0.21$ miles (1110 feet)
For 20dB desensitization	$D = 0.12$ miles (633 feet)

Therefore a mobile within .38 miles of the Part 15 installation has the ability to desensitize the device. The interference from the LMS mobile will be short and infrequent and can be improved by the use of directional antennas.

It is clear, even from this single case analysis, that, in general, the LMS system will probably suffer more from interference than the Part 15 will suffer from LMS systems.

5.2. Interference with indoor Part 15 Devices.

Work carried out on the radio coverage in buildings[3] has indicated a floor attenuation factor, f, at 864 MHz, in a building as

$$5.5\text{dB} < f < 15 \text{ dB} \quad \text{or } f = 10 \text{ dB with a standard deviation of 5 dB.}$$

CCIR Report 567-2[4] indicates a similar figure, for typical steel and concrete and stone office buildings, of 10dB with a standard deviation of 7.3 dB. In a severe case, with steel shell buildings, the attenuation was 28.5 dB mean.

Thus, using the 'Egli' propagation formula, the received signal level, at the fixed site, is

$$Pr = Pt - 114.7 - 20 \log F + 20 \log h1.h2 - 40 \log D - f \quad \text{dBm}$$

Assuming Pt is 200mW,
for $h1 = 200$ft, $h2 = 6$ feet, $F = 920$ MHz, and $f = 10$

$$Pr = -99.4 - 40 \log D \quad \text{dBm}$$

Assuming that the fixed site antenna gain is 9 dB,

$$Pr = -90.4 - 40 \log D \quad \text{dBm}$$

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[3]Cordless Telecommunications in Europe, Wally Tuttlebee (Ed.), Spriger-Verlag, Chapter 7, 'The Radio Channel", page 159.

[4]CCIR Report 567-2 "Methods and Statistics for Estimating Field Strength Values in the Land Mobile Services using the Frequency Range 30MHz to 1 GHz".(1978-1982), clause 5.3. "Building penetration loss". Measurements carried out in Louisville, Kentucky.

Assuming that the fixed site has a 6dB noise figure, in order to desensitize the site the received signal needs to be -102dBm or greater,

thus

$$40 \log D = 11.6$$
$$D = 1.9 \text{ miles}$$

Therefore an indoor 1W Part 15 device, within about 1.9 miles, has the potential to desensitize the fixed site station if it is in-band.
For a 20 dB desensitization (-82dBm), D = 0.6 miles.

Thus, from this simple case, for a 1W transmission, it can be seen that the interference potential exists from indoor Part 15 devices, but it is less than that from outdoor devices. The signal from the indoor Part 15 device will probably experience some extra blocking and hence reduce the effective radiated signal. The interference from indoor Part 15 devices will probably be isolated events and can be corrected by correct power level settings and, if necessary, change of frequency channel.

6. Conclusions - Market Implications of splitting into 4 MHz bands

If a 4 MHz band is allocated for the MobileVision, Teletrac or Pinpoint systems, then their present designs are unusable. It would be anti-competitive in that it would favor only the SBMS system which could rely on their cellular telephone system in order to provide good capacity for the essential voice and data services. Reducing the bandwidth would reduce the capacity of other systems to such an extent that they could not offer a viable service able to satisfy the IVHS requirements.

MobileVision have conducted substantial market research, in addition to studying the Intelligent Vehicle Highway Systems (IVHS) plans and objectives. In particular, the detailed needs of the Advanced Traveler Information Systems (ATIS), and Commercial Vehicle Operations (CVO) have been studied. These studies showed that data and emergency voice were essential. For emergency roadside and consumer ATIS services, 64% of respondents required voice. In commercial, fleet, CVO services, 46% required voice, while IVHS saw real time voice and data as essential for CVO. The demand is for a combined data, voice and location service. Indeed, if location only is offered, then there is only a 9% demand. Clearly the requirement is for a combined, real-time data, voice and location service. These services are, in fact, mandatory for IVHS services in CVO and ATIS where real-time voice and data services, in addition to location are essential.

The MobileVision system has been designed to offer all the services in one package so that it can compete in the market place and offer an exciting new service.

The MobileVision system has been designed, from the onset, to satisfy the FCC Interim rules and to satisfy the market requirements.

The proposed reduction of allocated bandwidth from 8 to 4 MHz is incorrect for technical, marketing and business reasons. It would allow SBMS to operate a system in conjunction with their cellular systems but prevents MobileVision from offering a comparable, if not better , service. This is clearly anti-competitive.

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Technical Review
of Hatfield Associates'
"Review and Discussion of the Pinpoint ARRAY Network and Its Performance"

Summary

Hatfield Associates have prepared a Review of the Pinpoint system that contains a Pinpoint system description plus some comments on trials carried out in the Washington D.C. area. In this trial a compact cluster of stations was set up, within 3 miles of each other, and a tight circular route used as the test route. An Amtech toll booth system was also set up in order to measure the mutual interference. The positioning and results from this test are rather misleading. The MobileVision analysis, detailed in Annex 3 of its Reply Comments, July 1993, was proven accurate in that the Amtech, Pinpoint and other AVM systems suffer from significant interference, and furthermore, that the Pinpoint system suffers more than the other AVM systems.

Without any analysis or comments on the validity of the tests, the conclusions are drawn that the Pinpoint system is "well-conceived and competently designed", "very robust", and "uses the radio spectrum efficiently". Both Pinpoint and Hatfield Associates would have been in possession of the MobileVision Annexes to the Reply Comments, (July 1993), which directly counters these conclusions. When critically analysed, the test results given in the Hatfield Review show that the Pinpoint system characteristics are:

- Poor location accuracy.
- Poor mobile receiver sensitivity.
- Short range on its forward link of only 3 miles, even though a 500W spread spectrum channel is used[1].
- Poor Jamming Margin of only 5dB.
- Lowest interference resistance to local area systems (Amtech) of all the systems.
- A unique dead-zone around local area systems (Amtech).

With a 500W spread spectrum signal, the propagation distance is shown to be 3 miles for the Pinpoint system. This result verifies the result of the MobileVision analysis that the Pinpoint system has very limited range[2]. Indeed it is worse than originally predicted because of the high mobile receiver noise figure. It is surprising that Hatfield Associates did not query the limited range compared to the use of a narrow band forward link. The use of a spread spectrum forward link is not shown to be efficient and in addition to limited range it is more liable to interference.

Using the analysis from the MobileVision paper, (Annex3 Reply Comments) the calculated distance for a mobile to interfere with the Amtech system is shown to be 434 - 772 feet.

[1]Pinpoint will need to deploy more than 4 times as many stations to cover an area compared to MobileVision.

[2]In the MobileVision test system in southern Florida, for example, the 200W narrow band command channel is reliably received by mobiles in excess of 20 miles from the station